International Journal of Innovations in Engineering and Technology (IJIET)
http://dx.doi.org/10.21172/ijiet.243.01

Analytical and Experimental Investigations of Solar Energy using Refrigeration and Milk Pasteurization Processes

Anand M. Sharan
Professor, Mechanical Engineering Department
Faculty of Engineering, Memorial University of Newfoundland, St. John's, Newfoundland, Canada

Abstract - This research work involves supply of heat to the generator of a refrigeration process where ammonia is used as a refrigerant and water is a solvent. The heat is supplied using the reflected rays from a paraboloid mounted on a solar tracking system. This method is more energy efficient than previously used flat plate solar collector. The process is applied for the Pasteurization of milk.

Keyword: Solar energy based refrigeration, Thermal absorption refrigeration, Pasteurization of milk.

I. INTRODUCTION

Over the past decades, there has been substantial growth in the demand for cooling, refrigeration, and air conditioning devices to fulfill various engineering and comfort requirements. According to the International Institute of Refrigeration (IIR), conventional vapor compression refrigeration systems (VCRS) consume some one-fifth of all the electricity generated worldwide. The consumption rate is anticipated to rise to half of the rate consumed by domestic buildings and commercial centers over the few coming years. [1]. The dramatic rise in energy consumption for such applications has exerted intense pressure on conventional energy sources so that the end of fossil fuels will come soon unless appropriate actions are taken immediately. Furthermore, the increasing demand for energy has risen the prices, emphasizing the need for increasing the supply of energy by either exploring new sources of energy or saving the existing sources of energy through reducing the energy consumption rate. The exploitation of renewable energies (*e.g.* the waste heat produced through industrial processes and wind and solar energies) to operate refrigeration systems has become an increasingly interesting field of research in recent years thanks to their sustainable yet abundant availability [2–5].

The enormous amount of energy consumed to power the compressors in the conventional VCRSs produces large volumes of greenhouse gases, contributing to many environmental issues. In addition, conventional refrigerants (*e.g.* hydrocarbons (HCs) and hydrochlorofluorocarbons (HCFCs)) for conventional VCRSs are known to contribute to ozone depletion and global warming. The international community has made significant efforts to protect the ozone layer and the ecological environment, including the restriction of the use of chlorofluorocarbons (CFCs) and HCFCs under the two important protocols adopted in 1987 (Montreal) and 1997 (Kyoto). Despite these efforts, the hole in the ozone layer has expanded from about 24,000,000 km^2 in 1994 to some 28,300,000 km^2, according to NASA [6]. Other relevant works can be seen in [7-10].

Based on the literature search above, it is clear that there is a need to replace fossil fuel based refrigeration systems with efficient solar energy based systems. So far, the researchers have used flat plate solar collectors to provide heat to the generator which is shown in Fig. 2 [11].

Therefore, the objective of this work is to replace the above solar collector with a paraboloid solar collector, which is far more energy efficient. The intent is to combine this work with an already published work by the author where it is shown that for cooling, the use of air coolers where ice is filled at regular intervals -is more economical method of cooling in place of air conditioners which consume far more energy [12].

II. USE OF SOLAR ENERGY IN REFRIGERATION PROCESS

Fig. 1 shows a paraboloid mounted on a tracking system. This paraboloid concentrates solar energy over a stand where one can place a receiver which can be a generator shown in Fig 2.

Fig. 2 shows refrigeration using absorption method. In this kind of system ammonia is the refrigerant and water is the absorbent. In the absorber, ammonia vapor coming from the evaporator is absorbed by liquid water. The formation of this liquid solution is exothermic. Since the amount of ammonia that can be dissolved in water increases as the solution temperature decreases, therefore, cooling water is circulated around the absorber to remove the energy released as ammonia goes into solution and to maintain the temperature in the absorber as low as possible. The strong ammonia- water solution leaves the absorber and enters the pump, where its pressure is increased to that of the generator. Afterwards, ammonia passes through the condenser, expansion valve, evaporator, and absorber where water is used as the solvent. From the absorber, the ammonia solution is pumped to the generator where heat is applied whereby ammonia vapor passes through the rectifier which removes any moisture from the ammonia.

Since the ammonia leaves the generator in the vapor state, ammonia solution in the generator gets diluted and this weak solution is returned back to the absorber through a valve as shown in this figure. Since, ammonia solution returning back to the absorber is at high temperature in the generator, a heat exchanges is used to recover heat from this solution in order to heat the pumped solution.

The reaction in the evaporator is endothermic, it causes cooling of the environment around the evaporator whereas the solution process of ammonia in absorber is exothermic. Therefore, water is circulated through the absorber to cool the solution thereby cooling by circulating water is to increase the solubility of ammonia in water.

In the generator, heat transfer from a high temperature source (heat from the sun) drives ammonia vapor out of the solution (an endothermic process), leaving a weak ammonia- water solution in the generator.

The only work input in this case is the power required to operate the pump, which is small in comparison to the work that would be required to compress the refrigerant vapor between the same pressure levels in vapor compression cycle in normal refrigeration process.

A rectifier is added between the generator and the condenser. The function of the rectifier is to remove any traces of water from the refrigerant before it enters the condenser. This prevents the possibility of ice formation in the expansion valve and the evaporator.

Fig. 2 shows the paraboloid mounted on Link 2. This link rotates about a horizontal axis passing through the point O2 which is located on Link 1. This figure also shows X0-Y0 and X1-Y1 sets of coordinate systems. X0 axis is horizontal whereas X1 axis inclined at an angle equal to the latitude of the place where the experiment is performed. The system is laid along the north- south line; the higher post is on the north side. The axis of rotation of the paraboloid is along the east west direction. The rotation rate of the Link 1 is at the same rate as the spin rate of the earth. The paraboloid is adjusted by rotation such that reflected rays shine on a receiver which needs to be placed on the stand. The parabloid is fixed with respect to the Link 1 i.e. while heating there is no relative motion between the Links 1 and 2 . The Link 2 is locked with respect to Link 1 for the day of the experiment. As the declination of the sun changes from the day to day, the angle of the Link 2 is altered and then locked during the experimentation. This way, the correction for the declination change is taken care of. This method of tracking is called the single axis tracking of the sun.

Fig 3 shows sun's rays incident on a parabola in an oblique manner i.e. , the rays are not parallel to the X axis. It shows the rays being reflected at an angle from the normal. Therefore, reflected rays also make an equal angle with respect to the normal. Another ray is taken incident at the same distance on the negative side of the Y axis. The two reflected rays meet at a point on the negative side of the Y axis. As the point of incidence shifts to the left, the directions of the reflected ray will go on changing.

For a parabola one uses equation [13]

$$y^2 = 4\,a\,x \qquad (1)$$

where the equation of tangent at a point (x1,y1) is given by

$$yy1 = 2\,a\,(x+x1) \qquad (2)$$

For values of a=50.0 , and x1= 7, y1 will be 37.41 for the upper part of the parabola , and -37.41 for the lower part.
If the rays are incident at 30 degrees from the X axis, the angle of the tangent for the upper part will be 69.49 degrees. The normal will be at 339.48 degrees. The angle of incidence will be 37.885 and the reflected rays will be at 294.229.
The equation for the reflected rays will be given by

$$y = -2.909\,x + 57.779. \qquad (3)$$

This equation for reflected rays for the lower part will be

$$y= 0.195\,x - 38.781 \qquad (4)$$

The above two equations show that the reflected rays have different slopes and that too – one positive and the other negative. Hence, they are converge as we go from left to right in this figure.

Fig. 5 shows this parabola displaced along the x axis by a distance equal to Qx , and the same along the y axis by Qy. There is no displacement along the z axis but the parabola is rotated about the z axis by an angle equal to 210 degrees in counter clockwise direction. The line joining the points O to O1 is along X1 axis in Fig. 1. The angle between X0 and X1 is equal to the latitude of the place of use. One thing to note is that the points P1 and P2 have moved to P1' and P2' on the parabola on the right.

To achieve this shift and rotation – one can use the transformation matrix [T1] as explained in Fig. 6 [13]. Here, Figs 6a to 6c show the rotation matrices about x ,y, and z axes respectively. Fig 6d is a translation vector having components Qx, Qy, and Qz whereas this matrix [T1] is a 4 x 4 matrix which can operate on a vector [V] and will rotate this vector in accordance with [Rx] or [Ry] or [Rz] whichever is selected, and translate by [Q].

To follow the sun during the day, one can use another transformation matrix [T2] which can be expressed as

$$[T2] = \begin{bmatrix} [R_x(\theta)] & [0] \\ [0] & 1 \end{bmatrix}$$

Therefore, the lines can be generated using the equation

$$[V] = [T2]\,[T1]\,[P2'] \qquad (5)$$

In Fig. 7 line AB is generated corresponding to ϴ =0, which is at noon. Other lines can be generated by substituting ϴ between -90 to 90 degrees. Similar computations can be performed for the point [P1'] by replacing [P2'] by [P1'] in Eq. (5). Fig. 8 shows a position vector of a point P2'. In a similar manner, one can define position vectors for other points to be used in Eq. (5).

Figs 9 and 10 show the end views of the lines intersecting at the receiver and the paraboloid ends. The ratios of the areas at the paraboloid end and the receiver end shows the concentration factor due to the paraboloidal reflection.

Fig 11 shows the experimental set up where the heating is performed within the receiver by the rays reflected from the paraboloid. Here, the receiver is stationary but the paraboloid is rotated to track the sun from the sunrise to sunset. There is no angular displacement in the position of points P1', P2' , and the sun. The center of the sun, and these two points lie in one plane as long as the sun shines. Consequently, the receiver gets the maximum possible energy during the sunshine hours.

The details about the tracking system and the automation of the process can be seen in [14-16].

When we compare this situation with that of the water heating system using the flat plate solar collector shown in Fig. 12, we find that the sun shines in the oblique manner on the receiving surface here and also, the intensity of the solar energy varies continuously as the sun moves during its daily motion. In this way, the heating in this case is highly inefficient for a given amount of solar heat flux.

Secondly, in Fig 12, the sun's rays heat a black plate covered by glass panes which are transparent to the radiative energy loss from the heated plate - to surrounding air. In comparison to this, in the paraboloid heating where the sun's rays directly heat the object which needs to be heated and this object is at a lower temperature. Therefore, less radiative loss will be there. Moreover, by concentrating the rays, we are reducing the glass areas of the receiver.

In the case of flat plate collector, the heat transfer between the plate and water flowing through the tubes incur convective thermal resistance in the tube flow, and fluid flow friction losses. These losses are not there in directly heating by the sun's rays as suggested in the present experiment.

The intent of this paper is to provide the heat to the generator in Fig. 2 for the refrigeration process. This will avoid fossil fuel combustion - such as combustion of propane or natural gas which results in global warming. In addition, it will be more economical due to its use of sunlight which is free rather than costly natural gas etc.

Ice making factories can be set up in areas outside the heavily congested cities and ice can be sold to people living in the cities. The author has published a paper as mentioned earlier where cooling using ice in an air cooler has been proven to be more economical than using air conditioners [12].

Another point is that there is a rush for producing green hydrogen using solar or wind energy where the green hydrogen is stored and transported. As far as cooling is concerned, making ice to be used for cooling - does the identical job. This process replaces such green hydrogen production if that hydrogen is to be used for power generation and then use that electricity to run air conditioners.

As far as storing of energy is concerned, it is much safer to handle ice as compared to the green hydrogen.

III. PASTEURIZATION OF MILK

Fig. 1 shows a receiver stand where heat from the reflected rays from the paraboloid are incident. Experiment was done by having a container of milk placed on the stand and heated to 72 ^{o} C for 15 seconds as given in Table 1 [17]. Then, this milk was transferred in another container filled with ice. Fig. 13 shows the heating process . In this way, one can successfully pasteurise milk using solar energy.

IV. CONCLUSIONS

In this work, the investigation of the refrigeration process was carried out both analytically and experimentally. This involved both heating and cooling. The experimental set-up for the refrigeration was then applied to the Pasteurization of milk.

Based on this investigation, the following conclusions can be drawn:

1. The thermal energy needed in the absorption type of refrigeration can be successfully used if a paraboloid is mounted on a solar tracking system and this method is much more thermally efficient than using a flat plate type solar collector.
2. If done this way, one can reach higher temperatures in the receiver than is possible by using a plate type heating process.
3. If the refrigeration is done this way then it would be possible for people having lower income to easily afford air cooling because they need not buy an air conditioners involving higher capital cost and higher operating cost. They can purchase ice manufactured by this process which is more economical than manufacturing ice using fossil fuels.
4. This process can be applied for the Pasteurization of milk.

REFERENCES

[1] Sur, A, and Das, R.K.," Review on Solar Adsorption Refrigeration Cycle, Int. J. Mech. Eng. Technol. (IJMET) 1 (2010) pp. 190–226.
[2] Siddiqui,M. and Said, S.," A Review of Solar Powered Absorption Systems", Renew. Sustain. Energy Rev. 42 (2015) 93–115.
[3] Wu,W., Wang,B., Shi, W. , and Li, X, "An Overview of Ammonia- Based Absorption Chillers and Heat Pumps, Renew. Sustain. Energy Rev. 31 (2014) 681–707.[
[4] Yabase,H. and Makita, K., " Steam Driven Triple Effect Absorption Solar Cooling System (2012).
[5] Yuan, Y. , Cao,X., Sun,L., Lei, B. and Yu, N, " Ground Source Heat Pump System: A Review of Simulation in China, Renew. Sustain. Energy Rev. 16 (2012) 6814–6822.
[6] M. Medrano, M. Bourouis,and Coronas,A. "Double-Lift Absorption Refrigeration Cycles Driven by Low–Temperature Heat Sources Using Organic Fluid Mixtures as Working Pairs", Appl. Energy 68 (2001) 173–185.
[7] Rogdakis, E. D. and Antonopoulos, K. A., "Absorption Diffusion Machines: Comparison of the Performances of $NH_3 – H_2O$ and NH_3-NaSCN" , Energy, Vol. 17. No.5. 1992, pp. 477-484.
[8] Bulgan, A. T., "Thermodynamic Design Data for Absorption Heat Pump Systems Operating on Amm onia -Lithium Nitrate" , Energy Conversion lv!anagement, Vol. 36, No.2, 1995,pp. 135-143 .
[9] Sun, Da-Wen, "Computer Simulation and Optimization of Ammonia- Water Absorption Refrigeration Systems, Ene1gy Sources, Vol. 19, No.7. 1997.
[10] Sun, Da-Wen, "Thermodynamic Design Data and Optimum Design Maps for Absorption Refrigeration Systems", Applied Thermal Engineering, Vol.17, No.3, 1996, pp.211-221.
[11] Theoretical and Experimental Investigation in Solar Absorption Refrigeration System (Ii Br –water) , https://theses.ncl.ac.uk/dspace/bitstream/10443/331/1/Dalichaouch89.pdf, p30.
[12] Sharan,A.M., 2022, "Design of Solar Energy Based Refrigerator ",International Journal of Engineering and Applied Sciences (IJEAS),ISSN: 2394-3661, Volume-9, Issue-2, pp. 20-22
[13] Craig, J. J.,1989," Introduction to Robotics, Mechanics, and Control ", Second Edition, Addison Wesley Publishing Company Inc, pp. 19-59.
[14] Sharan, A.M. , and Prateek, M. , 2006, " Automation of Minimum Torque Based Accurate Solar Tracking Systems Using Microprocessors ", Journal of Indian Institute of Science,86, Sept – Oct. , pp . 415 - 437
[15] Sharan , A. M. , 1997 , " Solar Tracking System ", U. S. Patent Number 5, 632,832
[16] Sharan, A., M., Zamanlou, M., Rahaman, M., H.,and Al-Mehedi, M., A., A., 2019 "CentralizedPower Generation of Solar Parks Using Wireless Controlling", International Journal of Current Engineering and Technology , , Vol.9, No.3 (May/June 2019), pp 405- 411
[17] Chaudhary, D. A., and Chaudhari,A. G., 2015, "Performance Evaluation of a Plate Type (HTST) Milk Pasteurization ", Research Journal of Animal Husbandry and Dairy Science, Vol 6, Issue 2, pp. 130-134.

TABLE 1 TIME-TEMPERATURE DETAILS OF THE PASTEURIZATION PROCESS [17]

Temperature	**Time**	**Pasteurization Type**
63ºC (145ºF)$^{1)}$	30 minutes	Vat Pasteurization
72ºC (161ºF)$^{1)}$	15 seconds	High temperature short time Pasteurization (**HTST**)
89ºC (191ºF)	1.0 **second**	Higher-Heat Shorter Time (HHST)
90ºC (194ºF)	0.5 seconds	Higher-Heat Shorter Time (HHST)

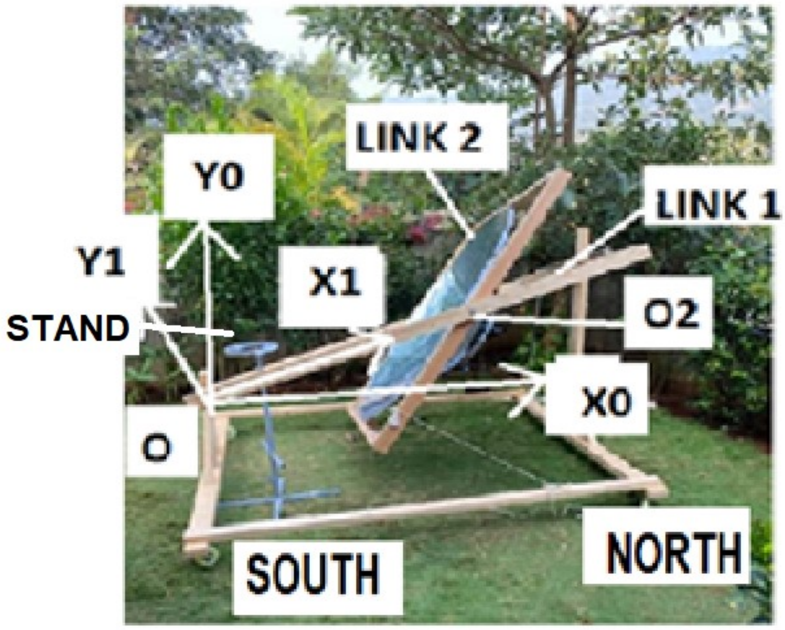


FIG 1 PARABOLOID MOUNTED ON A TRACKING SYSTEM

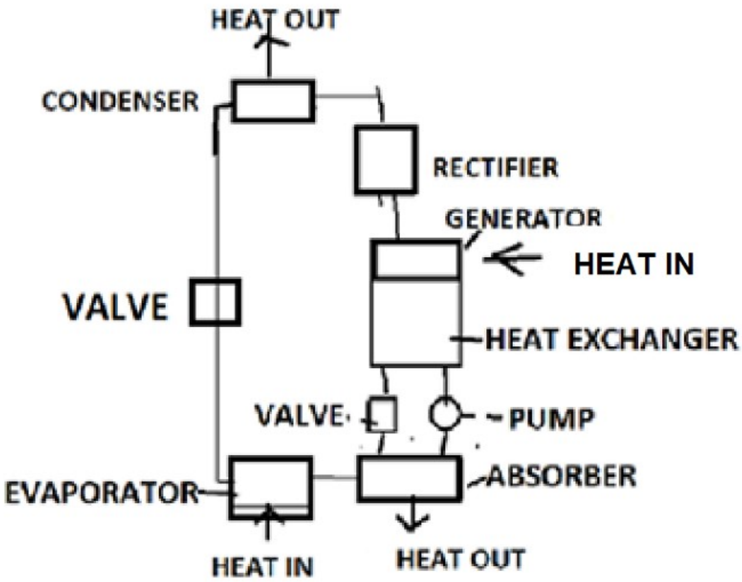


FIG 2 MODIFIED AMMONIA WATER ABSORPTION DIAGRAM

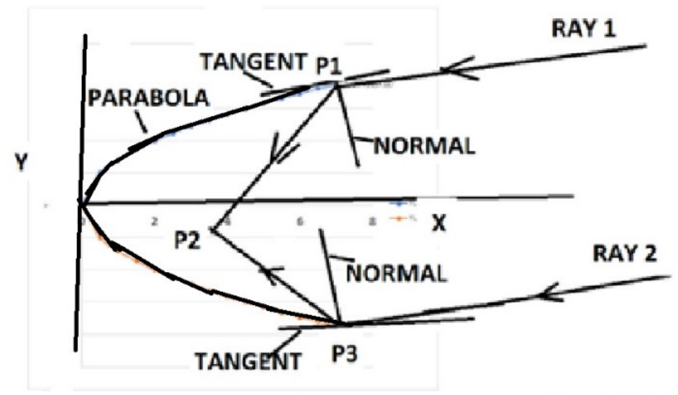


FIG 3 REFLECTION OF SUN'S OBLIQUE RAYS ON A PARABOLA

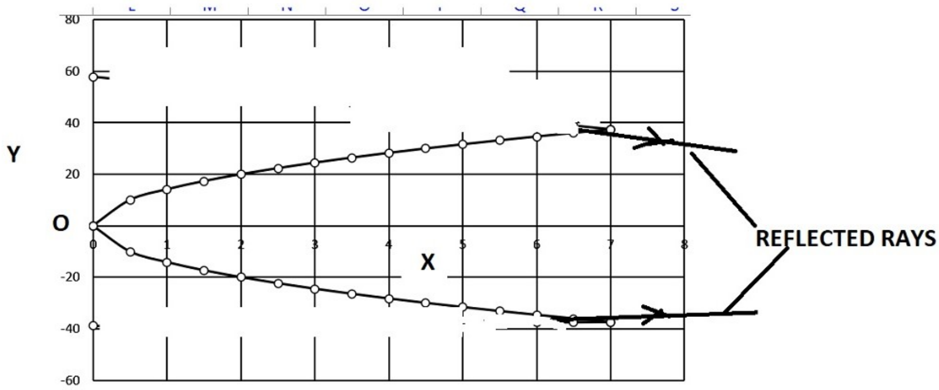


FIG 4 REFLECTED RAYS FROM THE PARABOLA

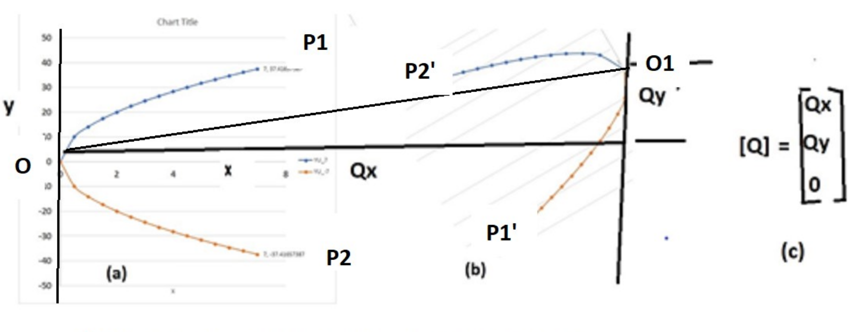


FIG 5 'RANSLATION AND ROTATION OF A PARABOLA

http://dx.doi.org/10.21172/ijiet.243.01

$$[R_z(\theta)] = \begin{bmatrix} Cos\theta & -Sin\theta & 0 \\ Sin\theta & Cos\theta & 0 \\ 0 & - & 1 \end{bmatrix}$$

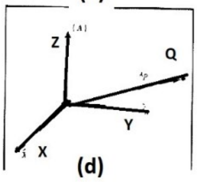
(a)

$$[R_x(\theta)] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & Cos\theta & -Sin\theta \\ 0 & Sin\theta & Cos\theta \end{bmatrix}$$

(b)

$$[R_y(\theta)] = \begin{bmatrix} Cos\theta & 0 & Sin\theta \\ 0 & 1 & 0 \\ -Sin\theta & 0 & Cos\theta \end{bmatrix}$$

(c)



(d)

$$[T] = \begin{bmatrix} [R] & | & \{Q\} \\ -- & -- & -- \\ [0] & & 1 \end{bmatrix}$$

(e)

FIG 6 DEFINITION OF VARIOUS MATRICES

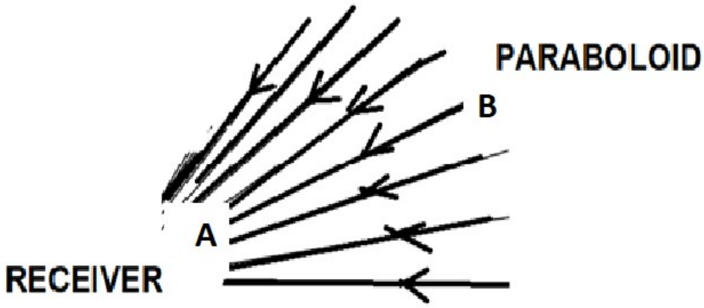


FIG 7 CONCENTRATION OF REFLECTED RAYS AT THE RECEIVER

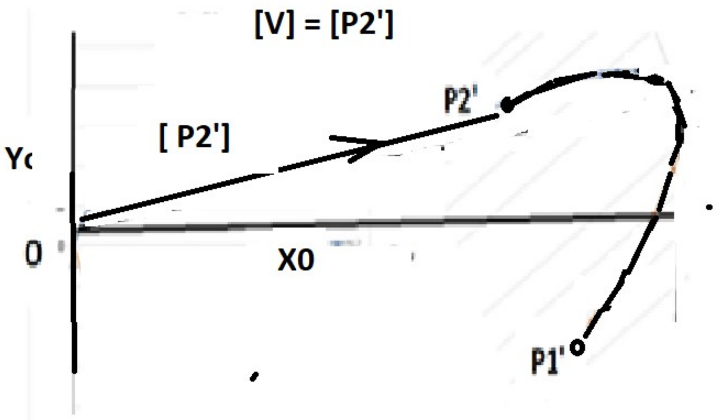


FIG 8 DEFINITION OF VECTOR [P2']

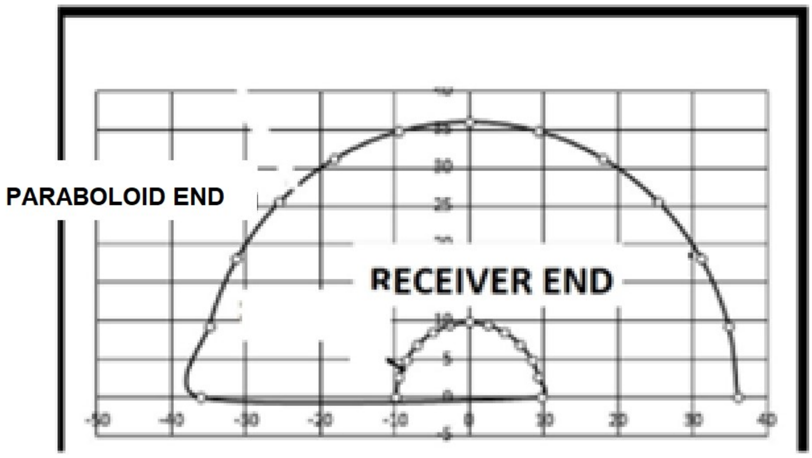


FIG 9 CROSS SECTIONS OF THE ILLUMINATED AREAS AT BOTH ENDS OF OF THEUPPER HALF OF THE PARABOLOID

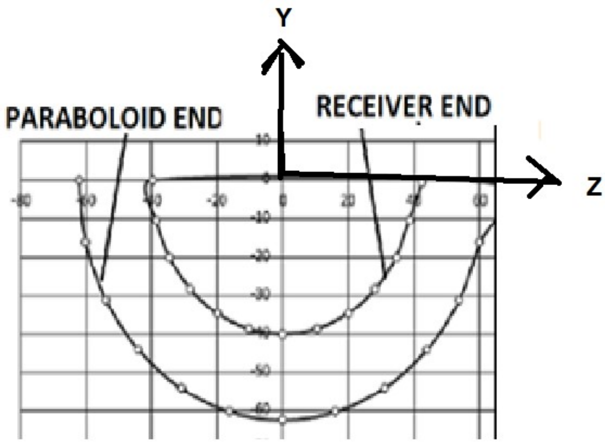
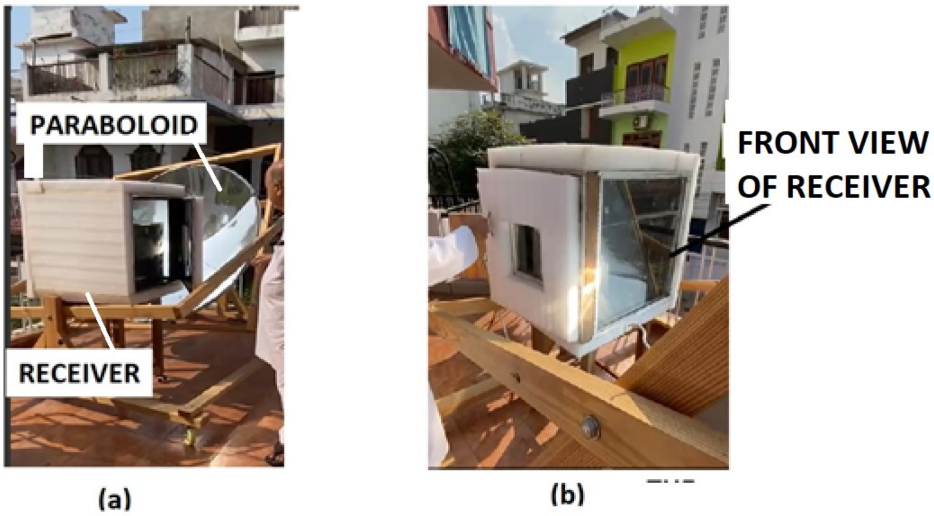


FIG 10 END VIEWS OF THE ILLUMINATED AREAS OF THE LOWER HALF OF THE PARABOLOID



FOG 11 SOLAR HEATING WITH A PARABOLOID AND A RECEIVER

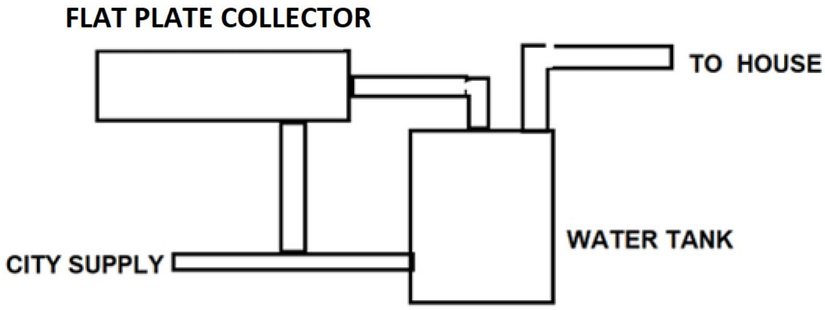


FIG 11

FIG 12 STATIONARY FLAT PLATE SOLAR COLLECTOR FOR SOLAR HEATING OF WATER

FIG 13 HEATING OF MILK IN THE PRESSURE COOKER BY THE REFLECTED RAYS FROM THE PARABOLOID